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ALKALI LANDS.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,
Washington, D. C., January 4, 1899.

SIR: The interest taken in the alkali work of this division in Montana during the summer of 1898 has been so widespread, and there have been so many requests for copies of a technical bulletin upon the subject, which is just about to be issued, that it has been thought proper to present the matter in a rather more popular style, leaving out some of the technical descriptions and the expensive illustrations, in order that it may have very wide circulation. This material, while almost entirely rewritten, is essentially the same as that contained in Bulletin No. 14 of this division.

I recommend that this be published as a Farmers' Bulletin.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

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INTRODUCTION.

Alkali and the treatment of alkali soils are subjects which are attracting very great attention at the present time, as alkali has already injured or is a serious menace to large areas of land. It is encountered in all arid districts the world over. It is always a source of uneasiness in such sections, for if the alkali is not apparent when the lands are first irrigated it is liable to appear after a few years as a result of the present system of irrigation. The uncertainty itself, and the serious nature of the trouble, calls for most energetic measures for the prevention of injury and the reclamation of ruined lands. Lands which a few years ago showed no signs of alkali, but, on the contrary, were extremely fertile, and upon which large amounts of money have been expended in farm improvements, are now, after ten, fifteen, or twenty years, being ruined by an accumulation of seepage waters and of soluble salts.

It is not intended at this time to undertake a general discussion of the alkali problem, as it will require many years of constant work to obtain an accurate knowledge of the conditions over the arid regions of this country. But the results of some investigations carried on during the summer of 1898 in the Yellowstone Valley are so important and of such widespread practical application and value that they are published in this form to help stimulate an interest in the subject, and to show, under certain conditions at any rate, that the means for the prevention of the rise of alkali and for the reclamation of alkali lands are well within the power of the farmer.

In taking up the study of the alkali problem the division was fortunate in selecting the Yellowstone Valley, where the conditions are as simple as can be found anywhere. There are many other areas in this country where the conditions are quite as simple, and where the matter can be brought under just such control as there, while there are much more difficult problems in other sections, due to location and topography of land, to the small available water resources, to the texture of the soil, and to the kind and distribution of the alkali.

THE CONDITIONS IN THE YELLOWSTONE VALLEY.

The investigations were carried on near Billings, Mont. At this place the Yellowstone Valley is from 6 to 10 miles wide. The valley is about 400 miles long in Montana, and irrigation is spreading from a number of centers within this area.

Irrigation has been practiced at Billings for the past twelve or fifteen years. The water for the main irrigation canal, supplying the valley at this place, is taken out of the Yellowstone River nearly 40 miles above the town of Billings. When the country was first settled (and, indeed, at the present time, in the area above the ditch) the depth to standing water in the wells was from 20 to 50 feet, and there were no signs of alkali on the surface of the ground. Under the common practice of irrigation, however, an excessive amount of water has been applied to the land, and seepage waters have accumulated in the soil to such an extent that water is now commonly found in wells throughout the irrigated district at a depth of from 3 to 10 feet from the surface. Many large tracts of once fertile lands on the lower levels are already flooded, and alkali has accumulated on them to such an extent that they are mere bogs, swamps, or alkali flats. This injury, while not very widespread as yet, has been so serious where the results have appeared, and the future is so uncertain that the owners of the land are naturally very much concerned. This is but too common a history of many large and fertile areas in Utah, in southern California, in Colorado, and, in fact, in nearly all of the older irrigated districts.

The valley at Billings is bounded on the north side by a sandy bluff of gray siliceous stone rising abruptly to a height of from 200 to 500 feet above the general level of the valley. On the south side there are steep, ragged hills of blue slate or shale. This shale dips down and passes under the sandstone bluffs about on a level with the present surface of the valley. The valley lands have been formed by the disintegration of both the sandstone and shale. In places the sandstone has been entirely worn away, leaving the soil formed from the disintegration of the shale exposed in places throughout the valley. This soil is stiff gumbo. The shale is very deep, borings for an artesian well having been made to a depth of 900 feet, and through the whole depth this shale has been found. In other parts of the valley the sandstone has not been so completely removed, and there are large areas of sandy or loam soils with the gumbo subsoil at a considerable depth below the surface. These areas are recognized as sandy soils, while the others are classed as gumbo. There are mixtures, of course, grading from one to the other, and these mixed soils are the most abundant in the valley.

Both the sandstone and the shale rocks contain large quantities of soluble salts, which are seen as shining crystals throughout the mass. The shale, however, contains very much more than the sandstone.

As the rocks have disintegrated through the influence of the weather the minerals have been broken down into simple mineral salts that have

remained as soluble salts in the soil. The reason for this accumulation is the small annual rainfall occurring in the arid regions. It is so little and the drainage is so slight that the salts accumulating from the disintegration of the rocks are not carried off into the ocean, as is the case in the soils of the humid regions. In the Eastern States, with an annual rainfall of 40 inches, nearly half of this leaches down through the subsoil and eventually finds its way through the streams and rivers into the ocean. This carries with it the greater portion of the soluble salts, as they are set free in the disintegration of the rocks. With less than 10 inches of rainfall, as occurring in the arid portion of the United States, the drainage is extremely small, and there is no natural means provided, therefore, for removing the salts as they are formed. This accumulation explains at once the wonderful fertility of the lands generally in the arid regions the world over, but it is also a constant menace because of the large amount of soluble salts which is liable to accumulate locally as the result of irrigation or as a result of other natural conditions not well understood, until they are a menace and often a destructive agency for the very lands which were formerly held in such esteem.

In the formation of the valley soils at Billings from the decomposition of the sedimentary rocks undoubtedly part of the soluble salts have been removed. Furthermore, as the drainage through the sandy soils is much freer than through the gumbo, and as there is less salt to start with in the sandstone rock than in the shale, it is natural to suppose that there is less of the soluble salts in the sandy soils of the valley at the present time than in the gumbo soils, and this is a fact proved by the investigations.

The alkali soils of the West are of two principal classes: The alkaline carbonates or black alkali (usually sodium carbonate) is the worst form, actually dissolving the organic materials of the soil and corroding and killing the germinating seed or roots of plants; the white alkalies, the most common of which are sodium sulphate, sodium chloride, magnesium sulphate, and magnesium chloride, are not in themselves poisonous to plants, nor do they attack the substance of the plant roots, but are injurious when, owing to their presence in excessive amounts, they prevent the plants from taking up their needed food and water supply.

The amount of soluble salts which plants can stand depends upon the character of the salt, the character of the soil, and the kind of plant. Hilgard states that few plants can stand as much as 0.1 of 1 per cent of sodium carbonate, or about 3,500 pounds per acre to a depth of 1 foot; of sodium chloride plants can stand about 0.25 of 1 per cent, and of sodium sulphate 0.45 to 0.50 of 1 per cent. Plants can stand less salts in sandy lands than on heavy clay or gumbo lands. It is a well-known fact that crops also differ in their ability to stand salts, and many crops will grow well upon soils on which others will not live.

Dr. F. W. Traphagen, of the Montana Experiment Station, finds that the composition of the salt appears to be quite uniform throughout

that portion of the valley which was examined around Billings. The following table gives the mean of five analyses which he made:

Composition of the soluble salts at Billings, Mont.

	Per cent.
Sodium sulphate	57.44
Magnesium sulphate	27.59
Calcium sulphate	13.05
Potash sulphate	1.55
Silica	.36
Total	99.99

The soluble salts at Billings are thus seen to be mainly sodium sulphate and magnesium sulphate, with none of the destructive sodium carbonate. There is but a trace, likewise, of sodium chloride. The soils all abound with calcium sulphate or gypsum.

It has been found that the solid grains of soil have the remarkable power of absorbing or concentrating a portion of the salts on their surface and thus withdrawing them from active solution. This is of the greatest practical importance, as otherwise the soil moisture would quickly become saturated with salts and rendered totally unfit for agricultural plants. As a matter of fact, in consequence of this condensing power, in no case was the concentration of the soil moisture found to exceed 3 per cent, although the salts were quite soluble and were crystallized out on the surface of the ground.

The investigations at Billings showed that when the concentration of the salts in active solution in the soil moisture is as great as 1 per cent the limit of most cultivated plants is reached. Further concentration kills all our ordinary agricultural crops. It was found, furthermore, that plants could just exist with 0.45 of 1 per cent of the soluble salts present, equivalent to about 15,000 pounds per acre-foot, and this is taken as the limit of plant production. The soluble salt content of soils in the humid portion of the United States ranges from 50 pounds per acre-foot in the sandy soils of the Atlantic coast to as much as 3,000 or 4,000 pounds in some of the heavier agricultural soils. The average amount would be considerably less than 1,000 pounds per acre-foot.

THE RAINFALL AND SEEPAGE.

There are no available records of the amount of rainfall at Billings, but at Miles City, about 130 miles northeast, the Weather Bureau records show an average annual rainfall of 12.8 inches. From May to September, inclusive, there are 6.7 inches, and during July and August 1.3 inches.

When the rains occur in the spring and wet the surface of the ranges, vegetation flourishes in the most luxuriant way and the grasses give very good grazing. The rains, however, appear to be only sufficient to wet the surface to a very slight depth; the water is quickly used up, and true desert conditions prevail during the summer time.

It appears that in the dry season the soil is moist from 3 feet down, but so slightly moist and the depth of the dry material is so great that it is altogether unlikely that the spring rains pass down to any appre-

ciable extent locally in any one year. The conditions, therefore, are unfavorable to a natural leaching of these soluble salts, except through the exceedingly slow movement there may be in the slightly moist subsoil.

HOW THE SALT DETERMINATIONS ARE MADE.

In the investigations of the conditions at Billings samples were taken with a long extension auger, and salt determinations were made for every foot in depth down to a depth, often, of 10 or 15 feet. The salt was determined by the electrical method, which has been described in previous bulletins of this division. The instruments used in this method are exceedingly sensitive, and determinations made by them are so very rapid that a large number of samples may be examined in the field. Examinations were made in the different types of soil, that is, in the sandy lands, in the stiff gumbo soils, and in the various intermediate grades that were found. Then several lines of borings were made above and below the irrigating canal and from the alkali flats back to the good lands in order to get an idea of the relation of the texture of the soil and the position of the irrigating canal to the alkali problem. Finally a very detailed examination was made of a section of land containing an alkali flat, and maps were constructed showing the distribution of the seepage waters and soluble salts at various levels under the surface of the ground. The value of such underground maps can hardly be overestimated. It is seen just where the seepage waters and the soluble salts are accumulating, from which direction they are coming, and just how drainage systems should be introduced to remove the trouble. They show which areas are safe for a number of years, those which will need careful attention to prevent the accumulation of salts, and those which need energetic measures for the reclamation of lands already damaged.

THE KINDS OF SOILS IN THE VALLEY.

The following table gives the mechanical analyses of a number of soils from Billings which indicate the difference in the texture of the soils which has been noticed.

Mechanical analyses of soils.

No.	Locality. (Miles from Billings.)	Description.	Moisture in air-dry sample.	Organic matter.	Gravel. (2 to 1 mm.)	Coarse sand. (1 to 0.5 mm.)	Medium sand. (0.5 to 0.25 mm.)	Fine sand. (0.25 to 0.1 mm.)	Very fine sand. (0.1 to 0.05 mm.)	Silt. (0.05 to 0.01 mm.)	Fine silt. (0.01 to 0.005 mm.)	Clay. (0.005 to 0.0001 mm.)
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
3756	2½ N	Sandstone bluff soil.	1.22	2.66	0.00	0.00	0.17	29.39	52.34	3.29	0.88	9.65
3322	11 W	Silty type, creek soil.	2.98	4.40	0.00	0.00	0.16	7.96	28.79	34.45	4.67	17.25
3309	5½ W	Sandy gumbo	1.56	4.66	0.00	0.00	0.20	11.72	45.05	14.69	3.49	19.90
3308	5½ W	do	1.94	3.30	0.00	0.10	0.46	15.61	39.59	14.63	3.38	21.30
3307	5½ W	do	2.35	3.72	0.00	0.02	0.32	21.37	38.27	8.99	3.13	22.55
3306	3 W	Gumbo	3.20	3.30	0.01	0.40	1.58	20.40	27.67	11.71	4.02	27.30
3769	5 W	Heavy gumbo	3.74	4.22	0.04	0.03	0.19	11.65	24.03	15.13	4.40	35.55

The first sample is a very pure type of sandstone soil taken from the top of the bluff about 2½ miles north of Billings and was derived from the decomposition of the soft layers of fine sandstone which cap the bluffs. These soils are very light and loose and have very free underdrainage. As a matter of fact they leach readily and, although they afford the best possible conditions for irrigation in that seepage waters are not likely to accumulate in them, it is probable that they would not last very long, as the soluble salts would easily and quickly be removed from them. Soils of this type are found in many parts of the valley, and there is little or no danger from seepage waters or from an accumulation of soluble salts at the surface, although they contain considerable quantities of such salts at depths below the surface.

The other samples in the table are seen to grade up through the mixed sandy gumbo to the pure form of gumbo with from 27 to 35 per cent of clay. The mixed soils are the most abundant in the valley.

SALT CONTENT OF THE SOIL.

Salt determinations made in the sandy type of soil above the ditch, where irrigation had never been practiced, and below the ditch, where irrigation had been carried on for ten or twelve years, showed that there was no excessive accumulation of soluble salts, but, on the contrary, that irrigation had really leached part of the salts out of the soil.

The following table gives the results of the salt determinations in a number of places in the sandy soil both above and below the ditch:

Soluble salt content in sandy land.

Depth (feet).	Unirrigated.				Irrigated.					
	Boring 62.		Boring 64.		Boring 26.		Boring 27.		Boring 28.	
	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.
0- 1	0.033	1,155	0.042	1,470	0.046	1,610	0.038	1,330	0.033	1,155
1- 2	.019	665	.041	1,435	.049	1,715	.045	1,575	.037	1,295
2- 3	.045	1,575	.035	1,225	.052	1,820	.044	1,540	.028	980
3- 4	.027	945	.038	1,330	.066	2,310	.051	1,785	.030	1,050
4- 5	.032	1,120	.045	1,575	.097	3,395	.060	2,100	.048	1,680
5- 6	.028	980	.055	1,925	.106	3,710	.051	1,785	.048	1,680
6- 7	.019	665	.056	1,960	.128	4,480	.064	2,240	.048	1,680
7- 8	....	....	.170	5,950	.147	5,145	.070	2,450	.047	1,645
8- 9	....	....	.238	8,330	.112	3,920	.049	1,715	.047	1,645
9-10	....	....	.243	8,505	.112	3,920	.049	1,715	.047	1,645
10-11	....	....	.205	7,175	.056	1,960	.072	2,520	.044	1,540
11-12	....	....	.120	4,200	.056	1,960	.072	2,520	.044	1,540
12-13	....	....	.163	5,705	.058	2,030	.072	2,520	.044	1,540
13-14	....	....	.228	7,980	.058	2,030	.072	2,520	.044	1,540
14-15	....	....	.178	6,230	.058	2,030	.072	2,520	....	....

The limit of excess of alkali in soils at Billings, as already stated, was found to be about 0.45 of 1 per cent. This is equivalent to about 15,000 pounds per acre 1 foot deep. It will be seen from the table that there is not sufficient soluble matter to a depth of 15 feet in this sandy soil to prevent the growth of agricultural plants. It is interesting to note that the amount of soluble salt in the upper 7 feet of the unirrigated

soil is particularly small; there is 50 per cent more, perhaps, than is ordinarily found in the soils of the humid region. Below a depth of 7 feet, however, the amount of salt is considerably increased. It would appear that there were evidences here of a slow downward movement of soil moisture, and that under these constant conditions of slow seepage the amount of salt in the upper layers of the soil was constantly diminishing. No examinations could readily be made of the soil below a depth of 15 feet, as this was the extreme length of the auger, but from information furnished by some well-diggers thoroughly familiar with the locality it was learned that the soluble salt content in wells above the canal increases below this to very large proportions. White layers, strongly impregnated with salts, are said to be found below this depth. The water from the wells contains too much of the salts to be of use for domestic purposes, although it is not so strong as to be harmful to cattle.

It is quite reasonable to suppose that the soluble salts had originally been uniformly distributed throughout the upper layers of these soils and that from storm waters and the slow seepage of the slight amount of moisture which the subsoil contains the soluble material had been washed down from the upper layers. Certain it is that similar results follow from the first effect of irrigation where there is good underdrainage, as generally prevails in this sandy soil. In the irrigated sandy land the amount of soluble matter, even to a depth of 15 feet, is comparatively small and the amount throughout the whole depth is quite uniform. This indicates very strongly that the salts have been leached out of the soil and carried off in the underground drainage waters. The examination of the water in a well situated in this irrigated area of the sandy land gives additional proof that some of the salts have been removed. There is a well at the southwest corner of sec. 2, T. 1 S., R. 25 E., near boring 44, in which the water contains 0.119 of 1 per cent of soluble matter, or 60 grains per gallon. Other wells throughout the irrigated area frequently contain as much as 0.4 of 1 per cent of salts.

The heavier type of soil—that is, the gumbo soil—was shown to be derived from the disintegration of the shale. The still undecomposed shale in the bluffs on the south side of the valley was found to be penetrated in every direction with veins of gypsum and the soft shale itself to be permeated with large quantities of sodium and magnesium sulphates. The soils resulting from the disintegration of the shale form a heavy, sticky, blue clay, quite impervious to water. The drainage is so slow through this fine, impervious material that large quantities of the salts remain in the soil.

On account of the poor drainage and the slow movement of the subsoil waters through this material there is great danger of overirrigation, and the problem of irrigation, which is easy on the well-drained, sandy lands, becomes far more complicated and much more difficult to manage on these heavy gumbo soils. Great care has to be taken not only in the application of water, but in the actual cultivation of these soils, as

they are liable to be ruined, for a time at least, for alfalfa. On account of the large water content, the fineness of the particles, and the amount of salts these soils contain they easily puddle and get still more impervious to water, and if they are worked when too wet clods form, and it is very difficult to reduce the field again to a good tilth.

On account of these properties the heavier or gumbo soils have to be farmed with very great care. Not only so, but there is great danger from seepage waters from neighboring plantations on higher levels. The soils themselves are naturally extremely fertile and very strong, and last very well if properly cared for. The following table gives the results of salt determinations in typical gumbo soil above the ditch, which has never been irrigated:

Salt content of a heavy unirrigated gumbo soil.

Depth (feet).	Per cent of salt.	Pounds per acre-foot.
0–1	0.035	1,225
1–2	.038	1,330
2–3	.054	1,890
3–4	.200	7,000
4–5	.333	11,655
5–6	.337	11,795
6–7	.253	8,855
7–8	.253	8,855
8–9	.282	9,870

It is apparent from the table that there is a considerable quantity of salt at a depth of 5 feet, and from there down. This boring, with others, is illustrated graphically in fig. 1.

When water is applied to the gumbo soil in the practice of irrigation, the first effect, as in the case of sandy land, is to reduce the amount of soluble salts in the upper layers of the soil. If there is good drainage, this excess of salt may be removed altogether from the soil. If the drainage through the gumbo is slow and inefficient, or, in the case of the sandy land, when underlaid with a compact gumbo subsoil where the drainage is poor, then, in the case of overirrigation, seepage waters will collect, owing to the inability of the soil to remove the water as fast as the excessive quantities are applied.

The following table gives the salt content from several places in one of the alkali flats so formed:

Salt determinations in an alkali flat.

Depth (feet).	Boring 36.		Boring 49.		Boring 52.	
	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.
0–1	0.757	24,710	0.792	27,720	0.229	8,015
1–2	.714	34,570	.920	32,200	.191	6,685
2–3	.634	21,105	.944	33,040	.182	6,370
3–4	.612	21,035	.792	27,720	.175	6,125
4–5	.589	20,965	.519	18,165	.159	5,565
5–6	.187	6,650	.519	18,165	.213	7,455
6–7	....	....	.357	12,495	....	....
7–8	....	....	.357	12,495	....	....
8–9	....	....	.292	10,220	....	....

It will be seen that in boring 36 the salt has accumulated to enormous proportions in the top 5 feet of the soil. The conditions show that the solution is so strong that a white crust is formed over the surface. However, on account of the absorptive powers of the soil, the solution immediately under this crust and in contact with the soil

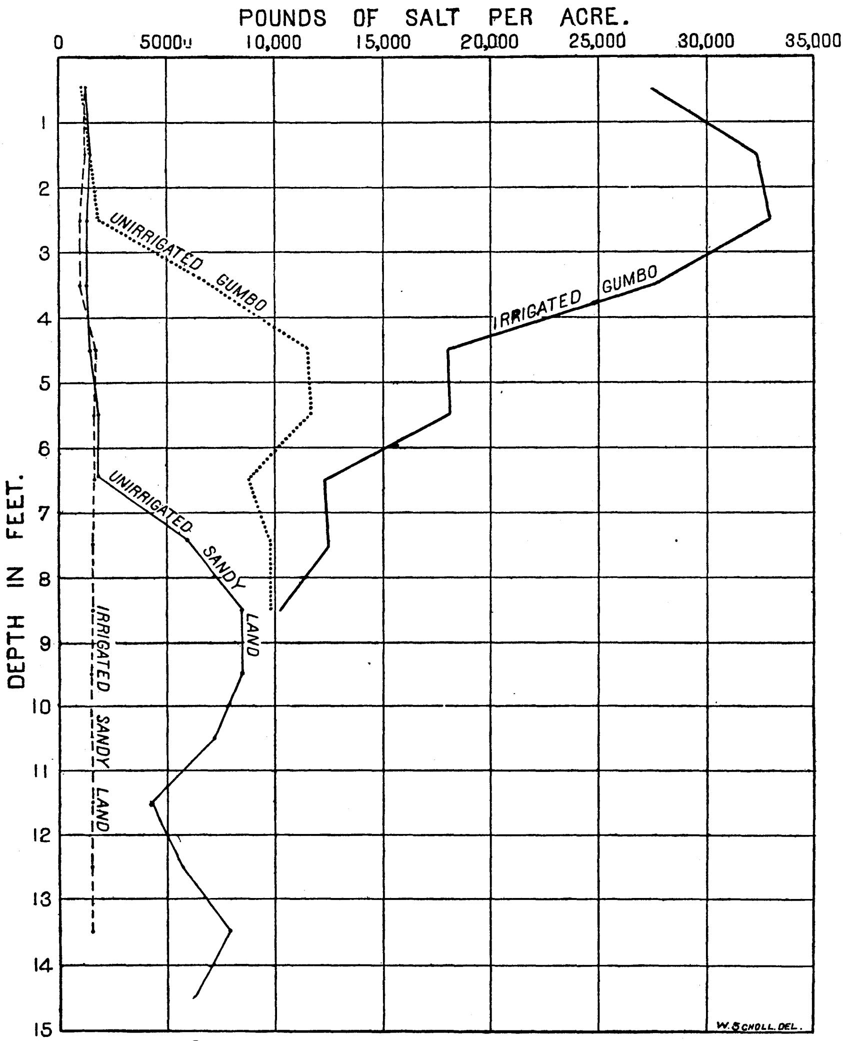

FIG. 1.—The salt content of sandy land and gumbo, with and without irrigation.

was only 3 per cent, notwithstanding the fact that the salt ordinarily is very soluble in water. This strength solution, however, is entirely too strong for any cultivated crop, and the alkali flat presented a very desolate appearance.

In boring 49, which was in the midst of the alkali flat, there was an excessive accumulation of alkali, beyond the limit of any agricultural

plant, at least to a depth of 7 or 8 feet. Below this it rather looks as though the amount of salts was diminishing and that if the boring could have been carried deeper the salt content would perhaps have grown less. At the present time the soil in boring 52 does not contain an excessive amount of alkali for alfalfa, but the level of standing water is so near the surface that the roots of the plants are submerged and the crop can not be successfully grown. This is the first stage in the ruin and devastation that is being wrought, and boring 49 shows the final and complete stage when the land is given up to water and alkali.

When land is in the condition of boring 52, and before any notable accumulation of crust has appeared upon the surface, the land becomes covered with a heavy growth of weeds. All agricultural crops have ceased to grow for some time, and the land has been abandoned as a barren waste. Such a condition as is shown by the growth of weeds is usually thought to mean that the alkali is disappearing or is being used up by the weeds themselves, and that the soil is again becoming fit for crops. In some cases this may be true, if there is sufficient drainage to carry off the excess of seepage waters and time enough be allowed for them to move on; but in many cases the conditions simply indicate that the weeds are a class of plants which can thrive on wet ground and grow for a while luxuriantly. If the methods of irrigation are kept up and the seepage waters continue to collect and evaporate for a few years longer, alkali will accumulate in sufficient quantities to kill even the growth of weeds, and the land will truly present the appearance of a desert.

From all the facts thus far observed it can be said that the first harmful effect of overirrigation in these soils is caused by excess of water, and if this is not immediately removed further damage will result from the accumulation of soluble salts. If the excess of water is soon removed no permanent damage will result.

A line of borings was run from the center of this alkali flat for a mile and a half back to the main canal. A number of borings were made to a considerable depth and salt determinations made for every foot in depth in each of these borings. It was found that adjoining the canal and for two-thirds of the way down to the alkali flat there is but little alkali, as though the irrigation water had removed the salts from this portion of the land and that they had then accumulated in the alkali flat, which is at a somewhat lower level. These irrigation waters slowly seep through the underground channels down into the natural drainage system, which is represented in this case by the alkali flat on account of its somewhat depressed condition. The water first appears in these low places in the line of underdrainage, and as the evaporation of the water goes on the salts accumulate, gradually extending up and enlarging the alkali flats as the water rises until the level of the surrounding area is reached, when the whole district is abandoned. The area around the alkali flat is first-class alfalfa land

and the property is considered very valuable, but only three or four years ago the alkali flat itself was considered just as valuable, and the alarming feature of the whole thing is that the owners know that if these conditions continue the alfalfa field itself will be ruined and will have to be abandoned in a few years unless very energetic means are taken to arrest the progress of the trouble.

The chances are, of course, that this condition has not arisen from the local application of water at this place. It is possibly a result of injudicious methods of irrigation on the adjoining lands at higher levels. One of the most discouraging features of the whole problem is that the owner of such a tract of land may use the most approved methods of irrigation and yet be completely ruined by the excessive and injudicious use of water by his neighbor. This neighbor may escape the injurious effects of his own crude methods, at least for many years after the other has been ruined. In the contemplation of such a problem as is presented in the Yellowstone Valley, therefore, there are certain property rights that may easily be abused, causing very disastrous results to appear upon a neighbor's land. It makes the whole problem very hard to deal with, especially as it would be extremely difficult to show the source of the trouble and to locate the offending person. It is a problem, however, which will have to be taken up; and if the property owners do not themselves take adequate care of their drainage systems and use intelligent methods of irrigation some means must be found of compelling them to do so or to give redress to their unfortunate neighbors.

This accumulation of salts is very harmful in the puddling effect on the soil. The flocculation of the soil grains is broken up and the grains are separated out into their most uniform position, where they offer the greatest possible resistance to the flow of water. This puddling can be relieved only by draining off the water and the salts, and this drainage is rendered difficult by their presence, so that the reclamation of these alkali flats on the gumbo soil is an exceedingly difficult, slow, and expensive undertaking.

The formation of these alkali flats is in a way an evidence of the effort of nature to correct the faults of our crude system of irrigation. The salts are being carried off into the natural drainage of the country, but the process is very slow and the excess of seepage water and the salts themselves collect in these places on account of the inability of the soil to let them pass as rapidly as the excess of water is supplied. This suggests the only feasible method of reclaiming these lands and, indeed, of preventing the accumulation of the salts which will occur except under the most careful and judicious methods of applying water. In cases like that under consideration, where the damage has already been done, the natural drainage is so slow that it does not afford adequate relief, and in fact is but a sign of impending ruin for a very much larger area. The only way to reclaim the land is to put in an efficient

system of drains, preferably of underground tile drains. It is urged against this idea that the land is not worth the cost of the investment in putting in a system of tile drains. This, of course, is an economic problem which is entirely dependent upon conditions of market, transportation facilities, and other commercial considerations. It may or may not be profitable at this time to protect the lands from destruction and to reclaim those that have been destroyed. It may be cheaper to move off into new areas, but the time will come, if it has not already come, when the land in the Yellowstone Valley and in similar situations will be worth the care and expense necessary to protect it from ultimate destruction. The amount of money now invested in the Yellowstone Valley is enormous, and the continuance of prosperity is entirely dependent upon the care which is taken in the methods of irrigating the lands. Property worth thousands of dollars may be ruined in a few years and become utterly worthless. The experience in the valley shows that this has been the case in the past, and there is much uneasiness felt in regard to large areas which show signs of the rapid spread of alkali.

EFFECT OF UNDERDRAINAGE IN REMOVING SALT.

There is abundant evidence that thorough underdrainage will reclaim these lands, and if introduced in time will prevent any such disastrous results as those which have been described. There has been no thorough system of tile drainage tried, but a few efforts have been made to reclaim the abandoned lands by open drains. That these have been efficacious the following investigations will show:

A drainage ditch had been dug in the alkali flat on section 2, T. 1 S., R. 25 E., and the excess of water had been continuously removed for some time before this investigation was made. A line of borings was made from this ditch back about one-fourth mile to see how the salt content had been changed. The results are given in the accompanying table, which represents the per cent of soluble salt found at different distances from this ditch.

Salt determinations at different distances from a drainage ditch.

Depth (feet).	Boring 45.	Boring 46.	Boring 47.	Boring 48.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
0–1	0.047	0.054	0.155	0.419
1–2	.030	.066	.164	.253
2–3	.036	.112	.177	.257
3–4	.031	.103	.213	.238
4–5	.045	.109	.191	.275
5–6	.045	.120	.191	.267
6–7	.043	.138	.225	.275
7–8	.043	.162	.237	.337
Average	.040	.108	.194	.290
Total pounds per acre 8 feet deep.	11,200	30,280	54,320	81,200

Boring 46 shows the amount of salt about 300 yards from the drainage ditch. The next column shows the amount at about 100 yards from

the ditch, while the last column shows the amount closely adjoining the ditch. It will be seen from this table how the salts have accumulated at the lowest point of the drainage system and how they are being removed by the drain as the water from the irrigating ditch seeps down and the excess of seepage water is carried off. The amount of salt found at the drainage ditch is already below the 15,000 pounds limit of crop production, while farther out in the alkali flat, under presumably the same conditions as existed at the drainage ditch when it was cut, the amount of salt is upward of 35,000 pounds per acre-foot.

It is easy to show in another way the beneficial effects of underdrainage. The land around Billings is underlaid at a depth of from 6 to 8 feet by a layer of gravel. Within the last few years it has been necessary to construct a ditch around the town of Billings to cut off from the town the seepage waters from the irrigated lands. This ditch is cut to a depth of 6 or 8 feet, so that it is in the gravel through its whole length, and it receives the water from two or three natural draws and all of the seepage water from four or five sections of land. No sewerage is allowed to flow into the ditch from the town.

A number of observations were made upon this ditch during the month of June. It was estimated that the average flow of water during this time was about 40 cubic feet per second. Frequent determinations were also made of the soluble salt content of the water flowing in this drainage ditch.

The following table gives the amount of salt found during the month of June:

Examination of drainage water.

	Salt (per cent).	Tons of salt removed per hour.
June 4	0.302	13.6
June 6	.424	19.1
June 7	.422	19.0
June 11	.449	20.2
June 12	.283	12.7
June 13	.481	21.6
June 16	.227	10.2
Average	.370	16.6

It will be seen that the ditch is doing a great work in removing the salt content from the overirrigated lands around the town. At the rate at which the salt was being removed at the time these observations were made the ditch was removing about 16½ tons per hour. If this rate was continuous it would drain 1 per cent of salt from the upper 5 feet of about 900 acres of land per year. As a matter of fact, while the ditch rarely if ever stops flowing, the flow is not always as great as during the time of this investigation. Still, the figures give some idea of the enormous results which may be accomplished by a judicious system of drainage in the reclamation of these alkali lands

and the protection from an undue accumulation of salt and seepage waters.

It may be well to state that the water in the main irrigating canal that is taken out of the Yellowstone River about 40 miles above Billings, although carried for this great distance through the valley, was fresh and free from salts. From all sources, however, where this water was escaping as seepage water it is seen to be loaded with excess of salts, and where free to flow off readily the salts will be carried off instead of accumulating in the alkali flats.

Besides the examination of the drainage ditch around the town of Billings many determinations were made of the salt content of springs and wells. The following table gives the determinations of the salt content from a number of places.

Salt content of springs and wells near Billings.

	Per cent.
Spring on the sandstone bluff	.029
Well on west side of sec. 2, T. 1 S., R. 25 E	.119
Spring on west side of sec. 2, T. 1 S., R. 25 E	.212
Well on north side of sec. 2, T. 1 S., R. 25 E	.309
Spring on north side of sec. 6, T. 1 S., R. 26 E	.433
Spring in center of sec. 5, T. 1 S., R. 26 E	.437
Well on south side of sec. 1, T. 1 S., R. 25 E	.536
Well on north side of sec. 2, T. 1 S., R. 25 E	.538

Well water containing more than one-tenth of 1 per cent is ordinarily considered unfit for domestic use. In most of these wells the water was less than 5 feet below the surface of the ground, and the water tasted strongly saline.

It will be seen, therefore, from all of these sources that the water in the soil is charged with this excess of salt. If there is a ready means provided for it to leave the soil, there will be no excess of soluble salts. It would, of course, be unfortunate to depend upon this to carry off the salts from reckless overirrigation, for in removing these salts much valuable plant food may also be lost and the soil in a measure impoverished. It is necessary, therefore, even with a system of efficient underdrainage, to use great care, so that there shall not be more loss through underdrainage than is necessary. It is perfectly evident, however, on the other hand, that if these conditions continue and the water rises closer to the surface than it is at present, that the seepage waters and the accumulation of salts together are likely to prove very disastrous over larger areas.

Many theories have been advanced by the land owners around Billings, and in these other localities also, as to the source of the alkali and as to the conditions under the surface. The belief is widespread that the alkali flats can probably be reclaimed by flooding the surface during a dry season and washing off the crust. Investigations, however, have shown very conclusively that the crust contains only a very small proportion of the alkali, and that this method alone will not be

sufficient to remove the trouble. Many of the planters are beginning to see that the rise of alkali is coincident with the accumulation of seepage waters, and to realize that the trouble is probably due to a too lavish use of water in irrigation.

Hilgard has pointed out for years that the only safe practice in bringing a new area under the ditch, in a soil that is at all likely to have alkali, is to use water very sparingly and keep the land under thorough cultivation, so that a minimum amount of water shall evaporate from the surface of the ground to deposit the salts, and so that there shall be no accumulation of seepage waters in the subsoil.

Hilgard has repeatedly called attention to the reactions between lime salts and the salts of the alkalies.

Where sodium or potassium carbonates or chlorides are associated with calcium sulphate in a well-aerated soil, a reaction takes place in which sodium or potassium sulphate and calcium chloride or carbonate are formed. The calcium chloride is extremely soluble and easily leached from the soil if there is any chance at all of its being carried off by drainage waters. The calcium carbonate is difficultly soluble and would remain in the soil as limestone. On the other hand, where sodium or potassium sulphate exists in the soil, together with lime carbonate and in the presence of an excess of carbonic acid or in the presence of supercarbonates of the alkalies, the reverse action takes place and carbonate of soda or potash is formed, together with the sulphate of lime.

Hilgard shows this reaction actually taking place in certain conditions of the soil. He points out that the carbonate of soda and sulphate of lime may occur in the bottom of a slight depression where the soil is moist, while the sodium sulphate and calcium carbonate will be found around the edges where the soil is better drained. As a practical application of this knowledge, he urges the use of gypsum or sulphate of lime in the reclaiming of lands containing the black alkali or carbonate of soda, and at the same time points out the necessity of thorough drainage in connection with the application of gypsum; otherwise the application will do no good at all.

These various reactions and properties of the so-called alkali salts indicate the methods for the reclamation of the alkali lands. In the case of the carbonates the course recommended by Hilgard is unquestionably the proper one—to treat the soil with heavy applications of gypsum and insure thorough drainage, so as to have the soil well aerated. In the case of an excess of sodium chloride, which is very soluble and easily leached out of a soil, it is only necessary to flood the soil and remove the excess of salt in this way. It is essential, however, that the soil so treated should have good underdrainage in order that the water applied at the surface may percolate through and actually carry off the excessive amount of the soluble sodium chloride. No application of any kind will be beneficial, as the sodium chloride is as

simple a salt as one can have and quite harmless, except when present in extraordinary amounts.

The treatment of soils containing sodium sulphate is more difficult than in the case of the chloride, as the salt is less easily leached from the soil. Here, again, no application, however, can be made, the sulphate, like the chloride, being injurious only when in large excess. It will be shown further on that the surest plan in the cultivation of these alkali soils is to use care in applying the water, so that there shall be no accumulation of the salts at the surface, and, as Hilgard has repeatedly recommended, the cultivation should be very thorough so as to prevent, so far as possible, the evaporation of the water from the surface of the ground. When the salts have once accumulated, however, there is nothing to do but wait for them to gradually leach away through the drainage and seepage waters or to thoroughly underdrain the land with tile drains, and so hasten the reclamation.

SUMMARY OF THE INVESTIGATIONS AND CONCLUSIONS.

The results of these investigations show that there is no sodium carbonate or black alkali in the soil. The source of the alkali is in the sandstone, and particularly in the shale or slate rocks from which the soils have been derived. Before irrigation was introduced the salts were present in the soils in rather large amounts, but well distributed, and not in such large quantities as to be injurious to crops. The injury is due entirely to overirrigation, to the translocation and local accumulation of salts by means of seepage waters, and to the imperfect drainage facilities in the compact gumbo soils and the inability of the excess of salts and of seepage waters to escape. The first trouble appears to be due to the seepage waters. This, of course, need not necessarily be so, but it appears to be the case in this locality. The open, sandy lands, having better underdrainage, are not likely to be injured by a rise of salts except from an excessive application of water or in the low places in the path of the drainage system, especially when these are underlaid, as they are liable to be, by the heavy gumbo subsoils. The gumbo soil requires great care in cultivation, as it is easily ruined by the accumulation of seepage waters and the subsequent accumulation of salts. There are many areas in the valley, of course, which have still a low or moderate salt content which are probably safe for years to come. There are other areas in which the salts are now accumulating to such an extent as to render the future value of the land very uncertain, while there are still other areas which have gone beyond this stage, and what were once fertile tracts have been thrown out as barren flats. The investigations show, further, the very disturbing fact that the injury need not be due to a local application of water, but to the injudicious application of large quantities of it in remote localities and on neighboring farms over which the unfortunate person has no control and for the effects of which he has, at present, no redress.

The investigations point clearly to the natural methods of preventing this injury and of reclaiming the lands when once the injury has occurred. There is no question that the injury is due to the translocation and local accumulation of the salts which were formerly well distributed in the soils of the valley. Alkali has been troublesome here only after eight or ten years of irrigation. The trouble is always preceded by an accumulation of seepage waters, followed in a few years by the alkali incrustations on the surface of the land. This evidently points to the necessity of great care in the application of water in the methods of irrigation. This care must be exercised not only for the land which is being irrigated, but for the adjoining lands on lower levels. While a man can overirrigate a sandy tract with practical impunity to himself, he is likely to swamp his neighbor on a lower level. There are involved property rights, therefore, which will come to be recognized and which will have to be taken into consideration in any intelligent and safe system of irrigation.

Where the damage has been done, or where the conditions are so imminent that ultimate ruin can be foreseen, the logical method of reclamation is in providing adequate systems of drainage to carry off the excess of water and the accumulated salts. This is expensive, but it is the only thing in this case to hasten the slow processes of nature, which are entirely inadequate in the presence of the present methods of irrigation and of culture. Underdrainage is expensive, but it has amply repaid for the investment in other localities where land is worth no more than in the Yellowstone Valley. Any land which is worth $50 per acre could well afford to be taxed for underdrainage if it is necessary, as in many places in the Yellowstone Valley, to save the investment from utter annihilation. It may be too soon yet to urge an extensive system of underdrainage in the valley, but some small systems should certainly be introduced, if necessary by cooperation, for an object lesson when it is considered necessary and timely to protect against trouble or to reclaim lands already abandoned. The owners will then see that it is feasible to protect their lands and to reclaim, through underdrainage, those that are abandoned.

It has been pointed out already that there are some crops which can stand much larger percentages of alkali than others. It is quite possible that other valuable crops can be found or can be bred which will stand large quantities of alkali, but it is unfortunate, indeed, for a locality like the Yellowstone Valley, which was originally free from alkali, to accept such conditions resulting from their injudicious methods of irrigation and try to find crops which will thrive upon lands which have been unnecessarily injured.

It must not be assumed, however, that a thorough system of underdrainage relieves one from exercising care and judgment in applying water to the land. There is less immediate danger of ruining the land, to be sure, but there are two things to be considered, namely, that an excessive use of water means just so much loss to irrigation and so much less

land which can be brought under the ditch, and also that in the removal of these salts by the flow of the seepage waters out through the drainage system large quantities of really valuable plant food are likely to be removed from the soil. The very accumulation of these soluble salts is due to the arid conditions of the climate. The great fertility of the soil results from the accumulation of these salts, and if we introduce artificial drainage, which will tax the resources of the soil, we may remove in the course of a generation, or even in less time than this, the accumulated results of the changes of vast geologic ages in the disintegration of rocks. By overirrigation and underdrainage we may remove in a few years the very conditions which contribute to the wealth of the country in the fertility of the soil.

In taking up new land in the Yellowstone Valley the heavy gumbo soils should be underdrained at the time the first irrigation waters are applied to the land. Even if the system of underdrainage is not complete at the start, a sufficient amount of it should be put in to answer the purpose at the beginning, and so arranged that it can be extended and more laterals put in as time goes on and the necessity of it becomes apparent. It is too late to wait until the damage has been done, for the accumulation of salts themselves acts on the heavy gumbo soils and makes them more impervious to water and harder subsequently to drain. Great care must be taken in the application of water. As little as possible should be applied at each time, so that there shall be as little waste as possible to go off as seepage water. The surface then should be thoroughly cultivated, unless otherwise protected from evaporation by alfalfa or other close-growing crops, so as to reduce the loss of water from the surface to a minimum and prevent thereby the accumulation of salts at the surface.

The rise in the level of water in wells must be looked upon with uneasiness and guarded against with great care.

The conditions in the Yellowstone Valley are particularly simple, and the danger from the rise of salts may be easily controlled. These investigations show the cause of the trouble, the actual conditions over a small section of the valley, and point out the logical methods of preventing trouble and of redeeming the land after the trouble has come. The locality is fortunate indeed in having no great excess of alkali in the soils previous to irrigation, as occurs over such large areas in adjoining States. The question involved is a simple problem, well within the control of the intelligent land owners of the valley.

While the discussion of this important subject in the present publication has been confined to the Yellowstone Valley, it is nevertheless one, as already stated in the introduction, of practical interest all through the States of the far West, and the principles applicable in the case under discussion are in general applicable to alkali lands throughout the country.

FARMERS' BULLETINS.

These bulletins are sent free of charge to any address upon application to the Secretary of Agriculture, Washington, D. C. Only the following are available for distribution:

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No. 18. Forage Plants for the South. Pp. 30.
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No. 21. Barnyard Manure. Pp. 32.
No. 22. Feeding Farm Animals. Pp. 32.
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